and social factors, it has the major disadvantage that different alternatives are very difficult to rank and compare on the basis of physical quantities alone; for example, what is the relative value of a tonne of rice as against a busload of tourists? A quantitative physical evaluation is therefore usually undertaken as the preliminary phase to a detailed economic evaluation. It may also be a very useful supplement to an economic evaluation, particularly when broadly similar land-use alternatives, such as various types of agricultural land use, have significant environmental and/or social consequences.

A full economic evaluation requires a detailed analysis of all the costs and benefits associated with existing or potential forms of land use and their expression in common and readily comparable monetary terms. The particular advantage of this approach is that the use of dollar values provides a universal and readily understandable yardstick for the objective comparison and ranking of entirely different categories of land use. To consider an example used in the preceding paragraph, it is the only really effective basis by which a tonne of rice *can* be compared with a busload of tourists.

A full economic evaluation requires the determination or estimation of all the costs and benefits associated with each alternative, expressed on a dollar basis. For comparison and ranking purposes, it is preferable to use the present worth of the net benefits associated with each alternative as the principal measurement unit. Acceptable alternatives, which are sometimes better understood by decision-makers and the community at large, are annual net benefits, capitalized net benefits, or benefit/cost ratios. As has already been indicated, there is a substantial toolbox of economic analysis techniques now available for the estimation of the equivalent costs and benefits associated with inputs and outputs which are not directly measurable in dollar terms. Where market values are not readily available, for example, opportunity costs and shadow prices may provide an appropriate substitute. Again, the environmental benefits associated with the adoption of conservation farming practices might be assessable in terms of the improvement in property values that results from such a change. In other circumstances, the concept of "willingness to pay", widely used in the assessment of water resources development projects, might be applied to obtain dollar values for many non-productive forms of land use such as nature conservation or recreation.

It is essential in a detailed economic evaluation to take proper account of the time-value of money by using appropriate discounting procedures. This requires very careful selection of the discount rates and project lives to be used in the assessment. The choice of an appropriate and rational social discount rate, relevant to the economic circumstances of the country or region in which the evaluation is being undertaken, is of particular importance, because the discount rate alone can significantly influence the ranking of alternatives and control the choice of the best alternative.

The purposes for which land evaluation surveys are undertaken, and the techniques used for this purpose, vary widely according to country requirements. In developing countries, and in sparsely-settled expanses of more developed countries, many broad-scale land evaluation surveys, encompassing whole regions or in some cases the entire country, have been undertaken on a reconnaissance basis. At a regional scale, extensive land evaluation surveys are often undertaken as a basis for major land-use change, such as the introduction of large-scale crop production or the development of a new irrigation scheme. In developed countries or regions, land evaluation studies may be undertaken for the purposes of planning for closer settlement or urbanization.

At the farm level, the particular technique known as land capability classification is very widely used to plan improvements in farm management, particularly for the purposes of sustainable agriculture and soil conservation. A modification of this technique has also been applied to the evaluation of land for the purposes of urban development. These techniques are readily applicable to integrated catchment management purposes.

An alternative approach has been developed for the assessment not merely of the *capability* of land for various land-use purposes, but more importantly of the *suitability* of land for specific land-use purposes. This approach, known as land suitability assessment, has now been extensively used, particularly in developing countries and at a regional scale, to assess the suitability of land for new forms of land development and choose preferred changes in land use. This approach is also appropriate for watershed management application. Both the techniques introduced above, viz., land capability classification and land suitability assessment, are discussed in further detail in the following sections of this report.

2. Land capability classification

Land capability classification is a form of land evaluation which attempts to assess the potential of land for specified uses. Originally developed by the United States Department of Agriculture (USDA) for farm planning purposes, particularly in areas prone to soil erosion, it has been applied in many countries, often in a modified form and extended to such activities as regional planning and urban land evaluation. It is a useful tool for integrated watershed management, particularly for the introduction and promotion of sound conservation farming practices but also for broader scale catchment land management planning, especially at the sub-catchment level.

The results of a land capability classification are usually presented in the form of a land capability map, which divides the land into capability classes. In the original and most commonly used form of the classification, there are eight major capability classes, ranking land-use potential on a "best" to "worst" basis for specified categories of agricultural uses. Within these classes, sub-categories indicating the nature of land-use constraints or conservation farming requirements may be included. The ranking of the classes is based on four major types of land use, which, listed in descending order of assumed desirability comprise:

(a) Land suitable for regular cultivation;

(b) Land suitable for grazing and occasional cultivation;

(c) Land suitable for grazing only;

(d) Land not suitable for agricultural production, but used for woodland production or reserved for uses such as nature conservation, water catchment or outdoor recreation.

The capability classes are presented as a hierarchy of "desirable" land uses, land which is allocated to a particular class having the potential not only for the use specified in that class but also for any of the classes listed below it. The classes used in the original USDA system, and generally used in other countries, are as follows:

(a) Class I· land suitable for regular cultivation where no special conservation measures are necessary;

(b) Class II: land suitable for regular cultivation but requiring simple (non-structural) soil conservation measures;

(c) Class III: land suitable for regular cultivation but requiring intensive soil conservation measures, such as graded banks and waterways;

(d) Class IV: land suitable for grazing and occasional cultivation; requires some non-structural erosion control measures;

(e) Class V: land suitable for grazing and occasional cultivation but requiring intensive (structural) soil conservation works;

(f) Class VI: land suitable for grazing only. Non-structural soil conservation measures required;

(g) Class VII: land which is steep, infertile, erosion prone or has shallow soils. Recommended use is green timber cover, some logging or grazing possible with good management controls;

(h) Class VIII: land which should not be cultivated, grazed or logged but set aside for such non-productive purposes as nature conservation, recreation etc.

Within each of these classes, sub-classes may be used to indicate the nature of the land-use constraints. In the original USDA system, the following sub-class categories were used:

e = erosion hazard

w = excess water problems

s = soil root zone limitations, such as shallowness, stoniness etc.

c = climatic constraints

Thus Class II land might be classified as IIe if it was erosion-prone, or Class V land as Vs if it had a soil depth limitation, and so on. Other sub-classes and other symbols might be used, depending on the region and the purpose for which the classification is being undertaken. The eight major classes might also be identified by other symbols than the Roman numerals used in the USDA system, depending upon local needs and preferences.

The individual capability classes categorize the land principally in terms of its limitations. Limitations are land characteristics which have an adverse effect upon, or otherwise restrict, the potential of the land for given uses. To determine its capability, land is classified first on the basis of its biophysical characteristics, the extent to which these characteristics will limit a particular type of land use and the current technology available for the management of land. The classification also incorporates the assessment of the soil erosion hazards which considers the appropriate level of land use, while avoiding environmental problems caused by soil erosion and sedimentation. The classification also outlines the types of land use appropriate for a particular area of land and the types of land management practices needed to prevent soil erosion and maintain the productivity of the land.

Land capability maps are determined from a consideration of climate, soils, geology, geomorphology, soil erosion, site and soil drainage characteristics, and current land-use data.

(a) For the farm management versions of the system, the determining climatic data are those which relate to plant growth and production, such as temperatures, the likelihood of the season being long enough for productive growth, and the availability of sufficient moisture.

(b) Soil types are assessed on their erodibility, the presence of any adverse soil physical or chemical characteristics, and the land management practices needed to maintain soil productivity and control soil erosion.

(c) Geomorphological data consider the slope gradient, slope length and shape, and terrain type. The terrain type and the shape of the slope, combined with a knowledge of the geology, can be used to infer particular soil types, or when combined with soils information, to define the boundaries of different soil types, such as the boundary of an alluvial flood plain. Slope gradient, slope length and existing soil erosion data are combined to assess the types of soil conservation practices necessary to prevent or to control soil erosion under differing land uses.

(d) Site drainage limitations determine the likelihood of flooding or prolonged inundation of an area. Soil drainage characteristics describe soil drainage conditions, soil permeability, and the nature of the groundwater behaviour. Site characteristics, such as the presence of various forms of soil erosion, rock outcrops and saline patches are also considered to determine the land capability of an area.

Land capability maps are presented at scales which vary according to their purpose. For farm planning applications, scales of 1.5,000 or 1:10,000 are generally used, depending upon the size of the farming property. Such maps are most conveniently prepared by plotting directly onto enlarged aerial photographs. More extensive mapping for regional planning purposes, such as has in some countries been undertaken for large rural regions or entire river basins, smaller-scale mapping at 1:100,000 is usual. For catchment management purposes, where mapping units are based on sub-catchments, intermediate scales of 1:40,000 or 1:50,000, probably airphoto-based, would be more appropriate.

The land capability approach described in this section, if appropriately modified to suit local farming practices and site conditions, provides a convenient way of assessing the potential of land for specified uses. It appears to be most valuable when it is used for its original purpose, *viz.,* farm planning, particularly where soil conservation is a primary objective. It is therefore of value for application to watershed management practice, where a focus on conservation objectives is essential. For use in the watershed management field it is probably still most appropriately applied at the farm planning level, although broader-scale mapping at the sub-catchment level is clearly desirable for the gaining of an overall, integrated picture of sub-catchment management issues and solutions.

In its original form, and the variants that have been applied in developed countries, there is a considerable focus on arable farming. In many catchment management situations this may not be an appropriate focus at all: there may be a requirement to focus on land uses such as forestry, nature conservation and wildlife preservation, water supply catchment reservation or outdoor recreational activity. In many parts of the ESCAP region very considerable modification of the classification categories might be necessary both for farm planning and for catchment management; in Java, for example, intensive rice paddy and tea production is to be found on steep country which in the original USDA system would be classified as Class VII or Class VIII.

A major shortcoming of the land capability classification approach, whatever modifications might be made to render it applicable to local conditions and practices, is that it is designed to indicate the *potential* uses of land, not the *most suitable* or *most preferable* uses of land. It is based essentially on an assessment of the limitations to the use of land, and it takes a negative approach in that it emphasizes which land uses are *not* appropriate on specific parcels of land.

An improved approach, which focuses on land uses and attempts to indicate the degree of suitability that a given parcel of land has for specified uses, is the technique known as land suitability assessment. This technique is the topic of the next section.

3. Land suitability assessment

Land suitability assessment is a process for assessing the relative *suitability* of indicated areas of land for specified land uses. The uses assessed may be any uses which are considered to be appropriate for the region under investigation; the system is by no means restricted to productive arable or grazing uses as in the land capability classification system. Originally developed by FAO in the 1970s for land evaluation purposes in developing countries, it offers considerable potential as a land-use planning and management tool for integrated watershed management purposes.

The results of a land suitability assessment are presented as a comprehensive set of documents, having three components comprising

(a) Detailed descriptions of each of the land uses evaluated in the assessment;

(b) A set of land suitability maps, indicating the relative suitabilities of the land mapping units on which the assessment is based for each of the land uses so detailed;

(c) A comprehensive statement of the beneficial and detrimental effects and consequences of applying each of the selected land uses to each of the areas of land mapped, including quantitative information about products and yields, input requirements, environmental and social consequences, and economic costs and benefits.

This amount of information provides a strong basis for rational decision-making regarding the best land uses for the area under investigation. For integrated watershed management purposes, this enables land management control and future land-use policy to be planned on sound environmental, social and economic grounds.

The original FAO classification system has four categories or levels of classification, in order of significance: land suitability orders, classes, subclasses and units. Land suitability orders provide a simple classification of land into two classes; "suitable", designated by the letter S, and "not suitable", designated by the letter N. The suitability classes break these categories down into three levels of suitability; "highly", designated by the numeral 1, "moderately", designated by the numeral 2, and "marginally", designated by the numeral 3. These levels are further broken down into suitability subclasses, which indicate the nature of any limitations that restrict the use of the land for the designated purpose. The subclasses are designated by lower case letters, such as "m" for moisture deficiency, "e" for erosion hazard, "d" for drainage limitations or "n" for soil nutrient deficiency. The lowest order, "suitability units", are further divisions of the subclasses which provide for differentiation on the basis of production characteristics or management requirements. These are designated by a dash followed by a numeral, e.g. "-2" Using this system, a land unit may be designated, by way of example, as S2e-2, indicating that it is moderately suitable for the indicated land use, but there is an erosion hazard which can be managed by farming techniques such as strip cropping. Detailed information regarding the required management techniques would be amplified in the descriptive material accompanying the land suitability maps.

For integrated watershed management applications, variations on this system of designation might of course be adopted to suit local conditions and appropriate forms of land use. In particular, a system which focuses on non-productive and protective land uses such as re-vegetation and destocking, water catchment reservation or nature conservation might require special emphasis in land evaluation for watershed management.

The broad procedures for undertaking a land suitability assessment are similar to those described generally in Section V.C.1, "Land evaluation", and Section V.C.2, "Land capability classification". The required field work and associated office investigations involves two parallel sets of activities: a detailed survey of the available resources of the land, and a detailed study of the relevant and appropriate forms of land use.

The resource inventory or natural resources survey should be land systems based and requires the collection of data relating to topography, landform, geomorphology, geology, soils, climate, hydrology, vegetation, fauna, existing land use, existing land degradation and land degradation hazard potential. The basis of such surveys has already been discussed elsewhere in this document, particularly in Sections V.B.1, V.B.2, V.B.3, V.C.1 and V.C.2 It should be re-emphasized that the specific objectives of any such resource survey need to be clearly identified and strongly articulated before any field work is undertaken.

The land-use study requires a detailed study of existing and potential land uses. This must involve a survey of existing land uses and their land requirements, as well as the consideration of possible future alternative land uses. This may require extensive consultation with existing landholders, with appropriate Government agency personnel and, if they are available, with agricultural and forestry consultants and other commercial advisers. A carefully planned and implemented programme of community involvement is an essential part of this process. A willingness to listen to all points of view and a large measure of imagination and lateral thinking are also essential if an appropriate range of alternative land uses is to be identified.

Once these land uses have been identified and described, it is necessary to establish in some detail the land-use requirements and limitations associated with them. These comprise such factors as climate, slope, orientation and exposure, soil types, soil moisture, drainage, nutrient needs and so on. Land-use requirements can be considered under two categories: land characteristics, which are attributes of land that can be measured or estimated in quantitative terms such as mean annual rainfall, slope, soil depth etc., and land qualities, which are attributes of land which act in a distinctive manner to influence its suitability for a specific land use, such as temperature regime, nutrient supply, drainage characteristics or erosion hazard. Land qualities depend upon the interaction of several land characteristics, which need to be identified as a basis for establishing the limits on land use.

Once the appropriate set of land characteristics and qualities for each of the land uses under investigation has been decided upon, these limits can be determined. Specifically, this requires the establishment of boundaries, using quantitative parameters as much as possible, between the suitability classes and subclasses adopted for the land capability assessment; i.e., the boundaries between S1 and S2, N1 and N2 and so on. Where this is done quantitatively the subsequent suitability evaluation mapping process can be greatly facilitated, particularly if the land resource survey mapping has been undertaken in terms of the same characteristics, e.g., slope, annual rainfall, effective soil depth etc.

The next stage in the suitability assessment process is to bring together the two strands of activity – resource survey and land-use study – to make the comparison between land uses and land which is the essential purpose of the assessment. The first step involves a detailed comparison and matching of the established requirements and limitations of the various kinds of land use under examination with the available qualities of the land, initially undertaken on a bio-physical basis. This must be followed by an economic and social analysis and a study of environmental impact. It needs to be supplemented by field checking, in which the provisional suitability classification is reviewed in the field by the landholders, agency personnel, consultants and others who were consulted during the initial stages of the land-use study.

It is important to emphasize that the process described above should be an iterative one, involving successive refinement and frequent feedback. Close contact should be maintained between the resource survey and the land-use study, and the specifications of land uses and their requirements progressively modified in the light of increasing or improving survey information. The iteration process might also involve progressive modification of the resource survey programme in the light of changing concepts of appropriate land uses and possibly, a modification of the original objectives of the evaluation project as needs and opportunities become clearer.

At the end of this process, the land suitability classification can be finalized and the presentation of the results undertaken. As indicated earlier, this generally involves three components: definitions and detailed descriptions of each of the land-use types examined in the assessment; a set of maps and accompanying legends showing the results of the land resource inventory and the land suitability classifications; and an assessment report detailing the suitabilities of each of the land-use types for each of the kinds of land available.

For regional or river basin scale assessments, an appropriate scale for the base land resource map or maps, detailing the basic land system units identified in the resource survey, is 1:50,000. For smaller upland watersheds and sub-catchments a larger scale, 1:25,000 or 1:20,000, might be more useful. The accompanying land suitability maps, showing the suitability classifications for each land-use type, can be prepared at the same scale, although where there is a considerable variety of land units and a large number of land-use types presentation at a smaller scale than the base map might be convenient. Each of the maps should be accompanied by a comprehensive legend summarizing basic biophysical data for each land unit and summary information for each land-use type.

Land suitability assessment, as described in this section, is considered to be far superior to land capability classification as a land-use planning and management tool for integrated watershed management purposes. This is because it provides detailed information about a range of feasible land-use management alternatives, appropriate to watershed management purposes, and presents the consequences of such changes in a concise but comprehensive manner, including their bio-physical, economic, social and environmental consequences It thus provides, in a convenient form, a sound basis for land-use planning, policy, management and investment decision-making. In the context of integrated watershed management for the ESCAP region, it has the added advantage that it was developed for, and has now been widely applied and proven in, developing countries in tropical and sub-tropical locations. Its adaptation to integrated watershed management applications across the ESCAP region therefore appears to be entirely appropriate.

An interesting regional application of this approach, which has been developed specifically for integrated watershed management purposes, is the Watershed Classification system used by the Mekong River Commission. This system, developed for the Commission by the University of Berne in Switzerland, was originally prepared for the purpose of watershed classification mapping for the watersheds of the Mekong River basin within Thailand. It utilizes a vector-based GIS mapping procedure, producing a series of three-dimensional topographical maps called Digital Terrain Models (DTM). Watersheds are classified and mapped in overlay form on this model according to five categories of recommended land use (i e., land suitability), which are as follows:

- protection forest
- commercial forest
- fruit tree plantation and agro-forestry
- upland farming
- lowland farming

The watershed category for a given parcel of land is calculated from an empirical formula which depends on five topographic or geological parameters, each of which can be mapped by the GIS model and shown on a coloured three-dimensional map model. The basic parameters used for this purpose are as follows:

- slope
- elevation
- landform
- soils
- geology

It should be noted, however, that in the original mapping undertaken for the Lower Mekong watersheds in Thailand, where soils and geological data were limited, the calculation of WSC was based on three parameters only, *viz.*, slope, landform and elevation.

The watershed classification classes can be shown in colour on the three-dimensional Digital Terrain Model or plotted in colour on conventional two-dimensional topographical maps called "WSC Maps". These maps usually prepared at a scale of 1:250,000. In addition to the WSC classifications, they also show elevation contours and river lines. They are therefore most suitable for macro-scale planning purposes at national, regional or large river basin level. The technique could however be easily adapted for smaller-scale mapping at the upland watershed level, provided that sufficient topographical and geological data were available.

This watershed classification system can be utilized for a variety of land-use planning and watershed management purposes, and appears to offer considerable potential for application to such purposes within the ESCAP region. Further information about mapping procedures and the application of these maps for planning and management will be found in the Mekong River Commission publication listed in the bibliography at the end of this document.

D. Data for hazard assessment

1. Data requirements for hazard evaluation

The data requirements for hazard assessment in connection with the identification of potential water-based natural disasters include the need for reliable and accurate data about such meteorological phenomena as rainfall and other forms of precipitation, wind, barometric pressure, temperature and humidity, along with hydrological data about run-off and streamflow, particularly in relation to flood events, and information about groundwater aquifer characteristics. Geological and geomechanical data, particularly in relation to the likelihood of landslide or other forms of mass movement, as well as detailed information about soil types and soil properties, are also necessary.

Within the ESCAP region, most nations now have reasonably well-established meteorological and hydrological data collection networks, although it is probable that in most cases these networks are not as comprehensive as they need to be for accurate forecasting of major water-based disaster events. Full implementation of the WMO World Weather Watch and Operational Hydrology Programmes will lead to the satisfactory provision of essential data requirements. The establishment and operation of these networks is an expensive, labour-intensive and on-going process that must be maintained into the future if the data collected are to be of continuing value; the longer data recording continues, the more valuable the recorded data become. These data are required for three purposes: firstly, as a record of past conditions, to provide a basis for the design of structures, devices or policies for disaster prevention or mitigation; secondly, to monitor existing conditions, as a basis for the forecasting of likely future conditions and particularly providing advance warning of oncoming disaster events; and thirdly, during the actual occurrence of disaster conditions, for accurate short-term forecasting of the likely time, magnitude and location of developing disaster events. Effective real-time warning systems, particularly cyclone and flood warning systems, may be as useful as high-cost physical structures and devices in reducing disaster damage costs and minimizing injury and loss of life during disaster events.

It is therefore of substantial importance that governments provide adequate funding for the establishment, operation and maintenance of comprehensive and effective data systems in relation to natural disaster phenomena. It is fortunate that the same data are necessary for a variety of other purposes, which in the context of this manual relate particularly to the requirements of data for integrated watershed management, land-use planning and management, natural resources development and management, and the maintenance of environmental quality.

2. Meteorological data

Meteorological data for hazard assessment need to be based on a comprehensive, nation-wide system of meteorological recording stations. It is highly desirable that such a system be funded and operated by the national government and not delegated to provincial or regional agencies. It is also essential that it be closely associated with, and compatible with, the national meteorological recording systems operated by neighbouring nations. WMO, with its 186 member countries, has laid down appropriate requirements in its programmes for meeting these needs.

The main categories of meteorological data needed for effective water-based natural disaster identification and assessment are briefly discussed below.

(a) *Precipitation data*

The precipitation data collection network should be based on a comprehensive system of daily rainfall measuring sites using standard raingauges. In an appropriate set of representative locations, and also on the catchments of critical flood-prone areas, the daily gauges should be supplemented by recording gauges providing a continuous record of rainfall depth and intensity. For preference, the recording gauges should be of the digital type so that data can be archived, processed and analyzed by computer and made readily available to potential users, particularly disaster-control agencies, through an e-mail or other Internet facility. Where recording gauges are located on flood-prone catchments as part of a flood-warning system, they should be of a type which provides for the immediate and direct telemetering of data to the headquarters of the disaster control agency.

In elevated watersheds where snowmelt may be a major contributor to flooding, it is desirable that well-designed recording snow gauges be located at selected sites. These should be supplemented by a network of snow depth and quality sampling sites at strategic locations on the catchment. In locations where hail is a hazard, the extreme difficulty of recording hail events mechanically can be partly overcome by careful observation of conditions during hailstorms and the making of post-storm damage surveys.

(b) *Wind and atmospheric pressure*

Detailed information about wind speeds and directions is essential for disaster management and mitigation in cyclone-prone areas. Point-site wind data need to be supplemented by regional or country-wide barometric pressure data for the preparation of synoptic weather charts and the assessment and forecasting of cyclonic, monsoonal or other storm and flood-producing rainfall events.

In cyclone-prone areas, an adequate covering of recording wind velocity and direction gauges is desirable. Such gauges should measure wind speed and direction continuously at a standard height of 10 m above the ground surface. For preference, the data should be recorded in digital form for the ready downloading and analysis of data and, desirably, for telemetered transmission to disaster control centres. A strategic location of wind recording instruments on the catchments of major flood-prone areas is also desirable for flood-warning purposes. The recording stations should be supplemented by three-hourly wind speed and direction observations at all principal weather observation stations.

Barometric pressures should also be observed at as comprehensive as possible a range of weather observation stations. At these stations, three hourly readings of atmospheric pressure are desirable. At key stations, recording barographs should be installed and daily radiosonde measurements of upper atmosphere pressures, wind speeds and directions and temperatures undertaken. Here again, the implementation of the observational programmes laid down under the various decisions of WMO would enable the fulfilment of these requirements.

(c) *Other forms of meteorological data*

There are several other categories of meteorological data which are of assistance in hazard assessment and particularly in the forecasting of hazard events. A variety of surface and upper atmosphere pressure and wind charts can be prepared from the basic data already discussed and these can be supplemented by cloud observations, satellite cloud pictures, radiosonde observations, radar observations, other satellite data and information reported by ships and aircraft. Temperature, humidity and dewpoint data are of considerable supplementary value in the prediction of storm rainfall conditions and the preparation of flood forecasting information, particularly if they include upper air profile measurements from radiosondes or aircraft.

3. Hydrological data

Hydrological data for hazard assessment ought also to be based on a comprehensive, nation-wide system of streamgauging stations. Because it is not possible to measure streamflow rates directly, the establishment of gauging stations and their progressive calibration or "rating" is an expensive, time-consuming and often long drawn-out procedure. For this reason, most countries within the ESCAP region have hydrological data collection networks which are inadequate in their areal coverage and are limited in the length of hydrological record available. In many cases these networks are operated by provincial or regional authorities, although it is highly desirable that they be made the responsibility of national governments particularly, as is the case in some parts of the region, where major river basins transcend the borders of two or more countries.

Streamflow measurement has two components. One involves the measurement of the depth of flow or "stage" at the selected gauging site, which preferably should be done on a continuous basis using recording instruments. There is a variety of such instruments available to suit site conditions; these include float recorders, pressure recorders, bubble-gauge recorders and a variety of electronic, electro-magnetic and sonic devices. For preference, these instruments should provide data in a down-loadable, digital form, rather than on charts, for ease and rapidity of analysis and archiving and, where appropriate, to facilitate the telemetering of data.

The other component involves the progressive calibration or "rating" of the site, to establish the relationship between the recorded depth of water and the corresponding volumetric flow rate in the stream. This requires periodical measurements of velocity distribution across the stream, from which, for a given area of cross-section, the discharge rate can be calculated. This procedure must be repeated over a range of flow depths to establish the stage/discharge calibration curve or "rating curve" for the station. Because high rates of flow will occur only infrequently, it may take many years to complete the rating curve. Furthermore, at many streamgauging sites the stage/discharge relationship is not constant, but changes either cyclically or even continuously so that a continuing rating process becomes necessary. For these reasons, it is highly desirable to maintain a trained workforce of hydrographic technicians available at short notice to undertake gauging activities.

Hydrological data are essential for a variety of purposes in relation to the management and prediction of water-based natural disasters. For flood control applications, good data regarding past flood events over as long a period of record as possible are essential for the design of all flood control structures and devices and the planning of non-structural flood mitigation measures. For flood forecasting and flood warning purposes it is highly desirable that streamgauging instruments be sited at key locations on flood-prone catchments, with provision made for them to be interrogated by telephone, e-mail or radio or alternatively, to download data continuously by one of these media to the flood control agency's operational headquarters.

Long-term streamflow data are also essential for the management and prediction of drought conditions and many aspects of water resources management and water quality management. For drought management, long-term streamflow or run-off data are necessary for the design of reservoirs and other flow-regulation devices and for the planning of drought management strategies.

In many localities within the ESCAP region, a key factor in drought management and drought preparedness is the availability of adequate supplies of groundwater, either as the principal source of supply or on a supplementary or emergency basis. Good data about the locations, depths, flow characteristics and quality levels of groundwater aquifers therefore form an important sub-set of the hydrological data requirements for disaster management in such localities.

4. Geological and geotechnical data

Geological and geotechnical data are of significance in relation to some aspects of water-based natural hazard assessment and in particular to land instability and land degradation.

A variety of geological and geophysical survey techniques is available for the investigation and assessment of slope stability and other forms of land instability hazard. The most basic requirement is for a broad-scale geological survey, undertaken in sufficient detail to allow for the identification of sub-surface conditions likely to be conducive to slope instability. Geological survey maps at a scale of at least 1:250,000 and preferably 1:100,000 are desirable for this purpose. The existence of land instability hazard zones can often be identified from remote sensing images, including aerial photography and, to less detailed extent, from satellite imagery. The use of these techniques has been discussed in Section V.B.3.

Within identified hazard-prone areas, more detailed geological, geophysical and geotechnical survey information is desirable. At reconnaissance level, electromagnetic surveys conducted from aircraft and particularly helicopters may be useful in locating hazard zones. Once they are identified, small-scale geophysical survey techniques, particularly seismic, electromagnetic induction and earth resistivity techniques, are particularly useful for locating and mapping shallow underlying strata, aquifer layers and other conditions conducive to slope instability. Within identified hazard-prone areas, soil and rock sampling is necessary to determine the engineering properties of the soils and underlying material, including particle size distributions and engineering classifications, shear strengths, permeabilities and drainage characteristics. Geotechnical mapping of these properties, to scales as large as 1:10,000, along with conventional soil survey mapping, is desirable within such zones.

Several of the forms of land degradation discussed in Chapter II are related to the physical and chemical properties of the surface soils, and the likelihood and potential severity of occurrence of these forms of degradation can be assessed from these properties, along with the geological, topographical and climatic features of the landscape at risk. This is particularly so in the case of water erosion, soil erosion and soil salinity.

The susceptibility of a soil to water or wind erosion is a function of many soil properties, of which the most important include particle size distribution, soil texture, soil structure, infiltration characteristics, in-situ moisture characteristics, shear strength, cohesion, and dispersibility. The likely erosion hazard can be assessed from standard soil survey mapping, particularly where the soil properties surveyed include those which influence erodibility or where there is an adequate local knowledge base regarding the erosion propensity of the soil types and profiles identified in the survey. For preliminary assessment, conventional soil survey data mapped at a scale of 1:100,000 provides a good starting point. Remote sensing photography or imagery, particularly black and white stereoscopic aerial photography at as large a scale as can be obtained, provides a very useful supplement. In most parts of the ESCAP region, erosion is already well developed in locations which are erosion prone and these areas are readily identified from aerial photography.

Areas which have been subject to land degradation as a result of soil salinity, whether dryland salinity or irrigation salinity, are also readily identifiable from aerial photography. In the early stages of salinization, characteristic changes in plant cover develop as salt-tolerant species replace the natural vegetation. In advanced stages, the absence or death of vegetation and the presence of white salt deposits on the land surface are readily identifiable. To identify a potential salinity hazard on land which is undeveloped or only newly developed, more detailed information based on a knowledge of soil properties and the underlying geology and geomorphology is required. Where sufficient information about the susceptibility of local soil types is available, conventional soil survey provides a good basis for hazard assessment, particularly where soil mapping has been undertaken at large scales,